Jun 27th, 3:25 PM - 3:45 PM

Session A3- Removing barriers at road crossings using stream simulation techniques in the northeast United States

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Princeton Hydro

Redesigning Road Crossings with Stream Simulation Techniques and MA Stream Crossing Standards

Fish Passage 2011
National Conference on Engineering
& Ecohydrology for Fish Passage

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Outline

- MA Stream Crossing Standards
- Stream Simulation
- Mitchell Brook Case Study

Massachusetts River and Stream Crossing Standards

- First 2006, Revised 2011
- Endorse Stream Simulation Approach
- Guidance / Performance standards
- Not prescriptive measures
- Major Goals:
  - Fish and other Aquatic Organism Passage (AOP)
  - River / Stream Continuity
  - Wildlife Passage

Massachusetts River and Stream Crossing Standards (2006)

- General Standards
  - Open Bottom or Embedded Culvert (1ft)
  - Natural bottom substrate
  - Span channel width (min 1.2 x BF width)
  - Low flow channel for comparable depths and velocities at low flows
  - Openness > 0.25 m
- Optimum Standards
  - Open Bottom Arch or Bridge
  - Span channel and banks (min 1.2 x BF + banks) with headroom for dry passage
  - Min height of 6 ft, Openness > 0.75 m (where wildlife passage is significantly inhibited)
  - Min height of 4 ft, Openness > 0.5 m

Massachusetts River and Stream Crossing Standards (2011)

- General Standards
  - Spans or
  - Culverts
    - Min 2ft Embedment
    - Min 2ft, 25% ()
    - 2 x D84
  - Span min 1.2 x BF width
  - Natural stream substrate
  - Match bedforms --> depths & velocities at varied flows
  - Openness > 0.82 ft (0.25 m)
  - Continuous Banks
- Optimum Standards
  - Bridge
  - Span 1.2 x BF width + Banks
  - Natural stream substrate
  - Match bedforms --> depths & velocities at varied flows
  - Min height of 8 ft Openness > 2.46 ft (0.75 m) (where wildlife passage is significantly inhibited)
  - Min height of 6 ft Openness > 1.64 ft (0.5 m)
  - Continuous Banks
    - Headroom for wildlife

Stream Simulation

- Developed in Washington State
- Detailed in USFS Manual
- Alternative approach to species-specific designs
- Avoids flow constriction during normal conditions
- Mimics diversity and complexity of natural stream channel through a crossing structure
  - Intended to accommodate normal movements of aquatic organisms
  - Presents no more of an obstacle to movement than the natural channel

Stream Simulation Design Elements

From *Stream Simulation: an Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings*

- Crossing Alignment
- Lateral Channel Adjustment
- Control Points US / DS
- Reference Slope
- Reference Bed Characteristics
- Bed Particle Size Distribution
- Bank Rocks / Isolated Boulders Sizes
- Bankfull Width
- Flood Capacity
- Bed Mobility

Case Study:
Mitchell Brook Culvert Replacement

- Conway Road crossing Mitchell Brook, Town of Whately, Franklin County, MA
- Tributary to West Brook
- Part of West Brook stream continuity study
- Several project partners
  - American Rivers
  - The Nature Conservancy
  - Conte Anadromous Fish Research Center (USGS)

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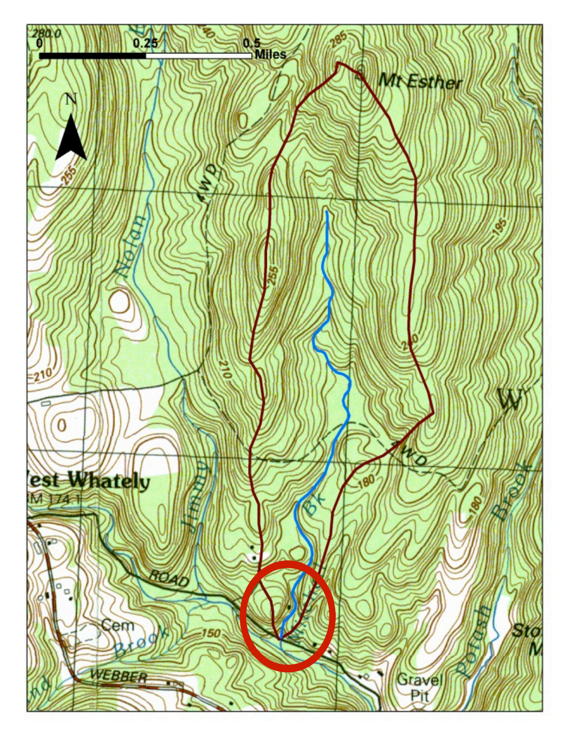
Mitchell Brook Setting

- Drainage Area – 225 acres (0.35 sq. mi.)
- Entirely forested watershed
- Gravel road, owned by Town



Site Assessment

- Existing perched 36" CMP
- Monitored eastern brook trout passage
- Gravel / cobble channel with bedrock influence

Site Assessment

- Geomorphic Survey
  - Cross-sections / Bankfull dimensions
  - Longitudinal profile
  - Wolman pebble counts
- Existing culvert slope – 5%
- Riffle slope US – 8%

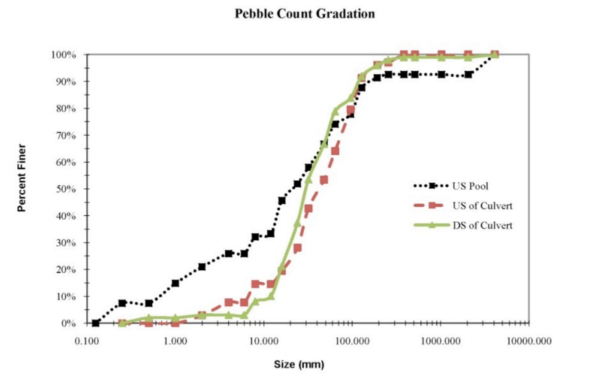


Figure 2. Particle size distributions for three bedforms in the project reach.

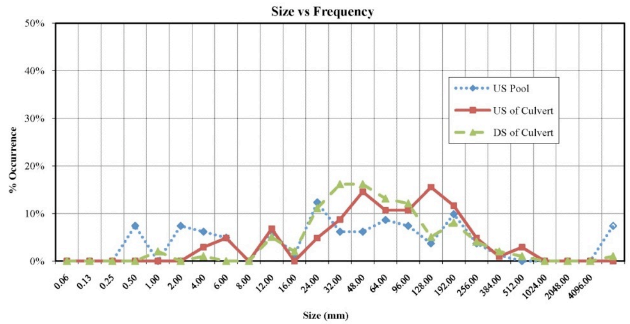


Figure 3. Frequency of occurence for particles in three bedforms in the project reach.

Design Constraints / Considerations

- Shallow cover over existing pipe
- Bedrock influence
  - Footings for culvert
  - Substrate stability, boulder embedment
- Steep reach – how to best simulate the bedrock influenced pool/riffle system
- Road width required for Town DPW future pavement section

Design Constraints / Considerations

- General standards attainable
  - Arch, Substrate, Width, Low flows, Openness
- Optimal standards would require significantly raising road elevation to achieve > 0.50m Openness and height standard

New England District, U.S. Army Corps of Engineers, Regulatory Division
Openness Ratio Spreadsheet

- Openness Ratio (OR) is calculated by dividing a culvert's cross-sectional area by its length: OR = x-sec area ÷ length
- Along with other criteria, the MA PGP, General Condition 21, states that to qualify for the Category 1 (non-reporting):
  1. New permanent stream crossings must have an OR ≥ .25

     $$OR = .25 = \frac{\text{(x-sec area)}}{\text{culvert length}} \quad \text{or} \quad OR = .25 = \frac{\text{[(x-sec culvert area pre-embed) - embedded area]}}{\text{culvert length}}$$
  2. Round culverts must be embedded at least 25%
- The chart below provides the diameter needed to meet the .25 OR for various culvert lengths, accounting for the embedded area, when embedding 25%. All calculations must be done in meters. The conversion to feet is provided.
- The Corps uses the .25 OR as a guide for Category 2 projects reviews.

Required Diameter for .25 OR & 25% Embedment					
Length		Required Open Area		Required Diameter	
(FT)	(M)	(FT^2)	(M^2)	(FT)	(M)
6	1.83	4.92	0.46	2.79	0.85
8	2.44	6.56	0.61	3.23	0.98
10	3.05	8.20	0.76	3.61	1.10
12	3.66	9.84	0.91	3.95	1.21
14	4.27	11.48	1.07	4.27	1.30
16	4.88	13.12	1.22	4.56	1.39
18	5.49	14.76	1.37	4.84	1.48
20	6.10	16.40	1.52	5.10	1.56
22	6.71	18.04	1.68	5.35	1.63
24	7.32	19.68	1.83	5.59	1.70
26	7.93	21.32	1.98	5.82	1.77
28	8.54	22.96	2.13	6.04	1.84
30	9.15	24.60	2.29	6.25	1.91
32	9.76	26.24	2.44	6.45	1.97
34	10.37	27.88	2.59	6.65	2.03
36	10.98	29.52	2.74	6.85	2.09
38	11.59	31.16	2.90	7.03	2.14
40	12.20	32.80	3.05	7.22	2.20
42	12.80	34.44	3.20	7.39	2.25
44	13.41	36.08	3.35	7.57	2.31
46	14.02	37.72	3.51	7.74	2.36
48	14.63	39.36	3.66	7.90	2.41
50	15.24	41.00	3.81	8.07	2.46

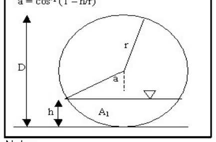
Derivation

1. The MA PGP, Category 1 requires:
   * 25% culvert embedment (=.25 x culvert diameter)
   * .25 openness ratio

2. Embedded area calculated as follows:

$$A_1 = \frac{D^2}{4}\left[a - \frac{\sin(2a)}{2}\right]$$

$$a = \cos^{-1}(1 - h/r)$$



Notes:
* a is in radians
* a = 60° = 1.05 radians, if h = .25D
* A_1 = embedded area

3. $OR = .25 = \frac{\text{[(x-sec culvert area pre-embed) - embedded area]}}{\text{culvert length}}$

where:
* x-sec area = $\pi D^2 / 4$
* embedded area for 25% embed = $.62D^2/4 = (A_1)$
* culvert length = L

Therefore:

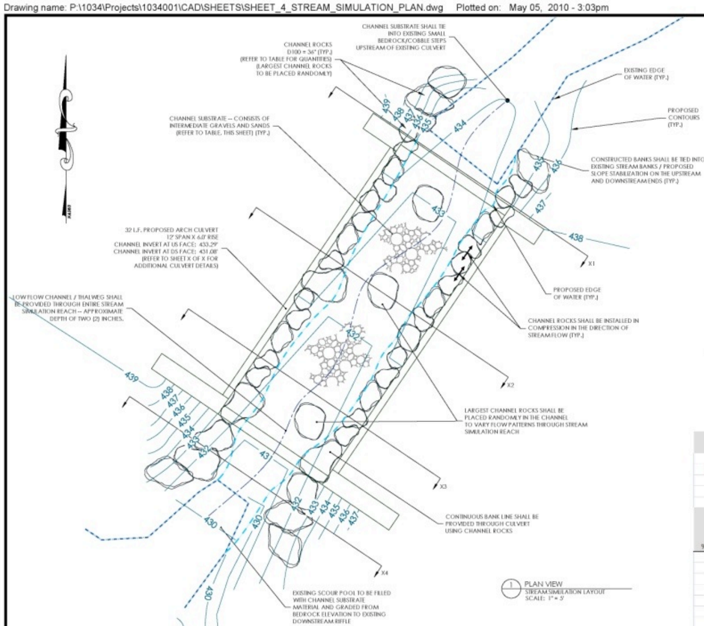
$$.25 = \frac{\pi D^2/4 \ - \ .62D^2/4}{L}$$

or

$$D = .63L^{1/2}$$

1/4/2006

Drawing name: P:\1034\Projects\1034001\CAD\SHEETS\SHEET_4_STREAM_SIMULATION_PLAN.dwg Plotted on: May 05, 2010 - 3:03pm

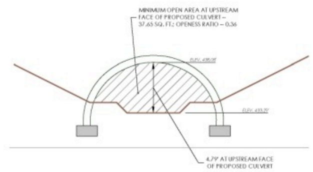


1 PLAN VIEW
STREAM SIMULATION LAYOUT
SCALE: 1" = 5'

NOTES:

1. FOR ADDITIONAL DETAIL ON PROPOSED GRADING, REFER TO SHEET X OF X. GENERALIZED PROPOSED GRADING (I.E. TRAPEZOIDAL CHANNEL) IS SHOWN AS A REFERENCE GUIDE FOR THE CONTRACTOR. DUE TO THE NATURE OF THE PROPOSED CHANNEL MATERIAL AND SUBSTRATE, ACTUAL FINAL GRADE SHALL BE ADJUSTED IN FIELD TO APPROXIMATE A MORE NATURALIZED STREAM CHANNEL.
2. FOR SOIL EROSION AND SEDIMENT CONTROL, REFER TO SHEET X OF X.
3. FOR CONSTRUCTION DETAILS OF CULVERT AND FOOTINGS, REFER TO SHEET X OF X.

GRAPHIC SCALE
0 1 2 3 4 5 10 20 FEET
SCALE: 1" = 5'



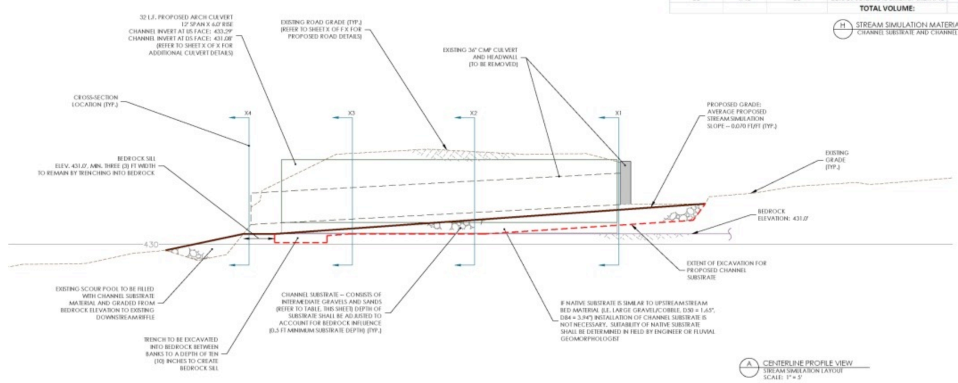
B OPENNESS RATIO DETAIL
SCALE: 1" = 5'

CHANNEL ROCK SPECIFICATION				
TYPE	ROCK CLASS	APPROX WEIGHT	MEDIAN AXIS	QUANTITY
BANK	ROCK-24	630	24" +/- 4"	80
RANDOM	ROCK-36	2,120	36" +/- 6"	10
			TOTAL WEIGHT:	**35.8 TONS**

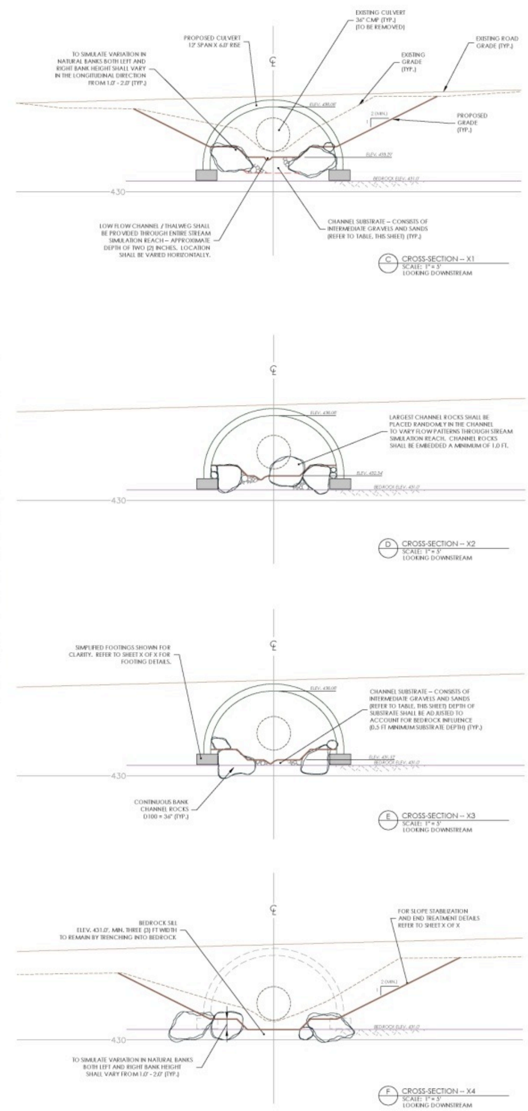
CHANNEL SUBSTRATE GRADATION SPECIFICATION				
% PASSING	US STANDARD SIEVE SIZE	% VOLUME	EXPLANATION	VOLUME CY
100	12"	5	4% of volume is 6" to 12"	1.3
95	6"	25	24% of volume is 3" to 6"	6.3
70	3"	15	15% of volume is 2" to 3"	3.8
55	2"	22	22% of volume is 3/4" to 2"	5.5
33	3/4"	25	25% of volume is #8 to 3/4"	6.3
8	#16	8	2% of volume is #40 to #16	2.0
			TOTAL VOLUME:	**25.0 CY**

FINE MATERIAL GRADATION SPECIFICATION				
% PASSING	US STANDARD SIEVE SIZE	% VOLUME	EXPLANATION	VOLUME CY
100	#8	50	50% of volume is #40 to #8	1.9
50	#40	50	50% of volume is smaller than #40	1.9
			TOTAL VOLUME:	**3.8 CY**

H STREAM SIMULATION MATERIALS TABLE
CHANNEL SUBSTRATE AND CHANNEL ROCKS



A CENTERLINE PROFILE VIEW
STREAM SIMULATION LAYOUT
SCALE: 1" = 5'



C CROSS-SECTION – X1
SCALE: 1" = 5'
LOOKING DOWNSTREAM

D CROSS-SECTION – X2
SCALE: 1" = 5'
LOOKING DOWNSTREAM

E CROSS-SECTION – X3
SCALE: 1" = 5'
LOOKING DOWNSTREAM

F CROSS-SECTION – X4
SCALE: 1" = 5'
LOOKING DOWNSTREAM

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PROJECT NOTES

1. TOPOGRAPHIC AND BOUNDARY SURVEY PROVIDED IN DIGITAL FORMAT FROM GM2 ASSOCIATES, INC., 16 BIRD STREET, SUITE 2A, TORRINGTON, CT, NOVEMBER, 2009.

2. VERTICAL DATUM IS NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88), FEET. HORIZONTAL DATUM IS NORTH AMERICAN DATUM OF 1983 (NAD83), FEET.

3. WETLAND DELINEATION COMPLETED BY JMM WETLAND CONSULTING SERVICES, LLC, 25 CHURCH HILL ROAD, NEWTOWN, CT 06470. WETLAND FLAGS WERE FIELD LOCATED BY GM2 ASSOCIATES, INC., OCTOBER, 2009.

DATE	DESCRIPTION

REVISIONS

GEOFFREY M. GOLL
Professional Engineer
MA Lic. No. PE-050997-E

DATE

PRINCETON HYDRO

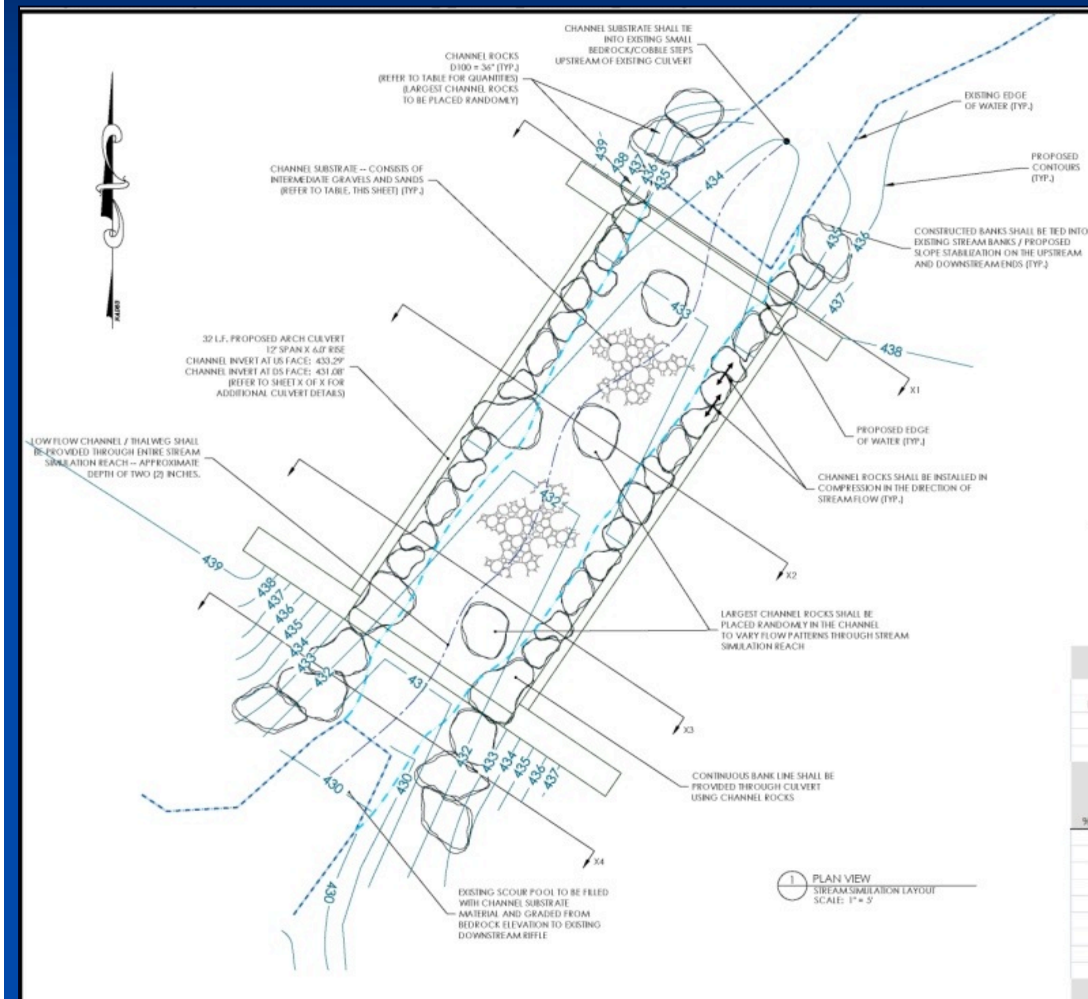
PRINCETON HYDRO, LLC
20 BAYBERRY ROAD
GLASTONBURY, CONNECTICUT 06033
PHONE. 860.652.8911
FAX. 860.652.8922
WWW.PRINCETONHYDRO.COM

PROJECT NAME/LOCATION:
MITCHELL BROOK AT CONWAY ROAD
STREAM SIMULATION CULVERT REPLACEMENT
TOWN OF WHATELY
FRANKLIN COUNTY, MASSACHUSETTS

DRAWING NAME:
STREAM SIMULATION PLAN

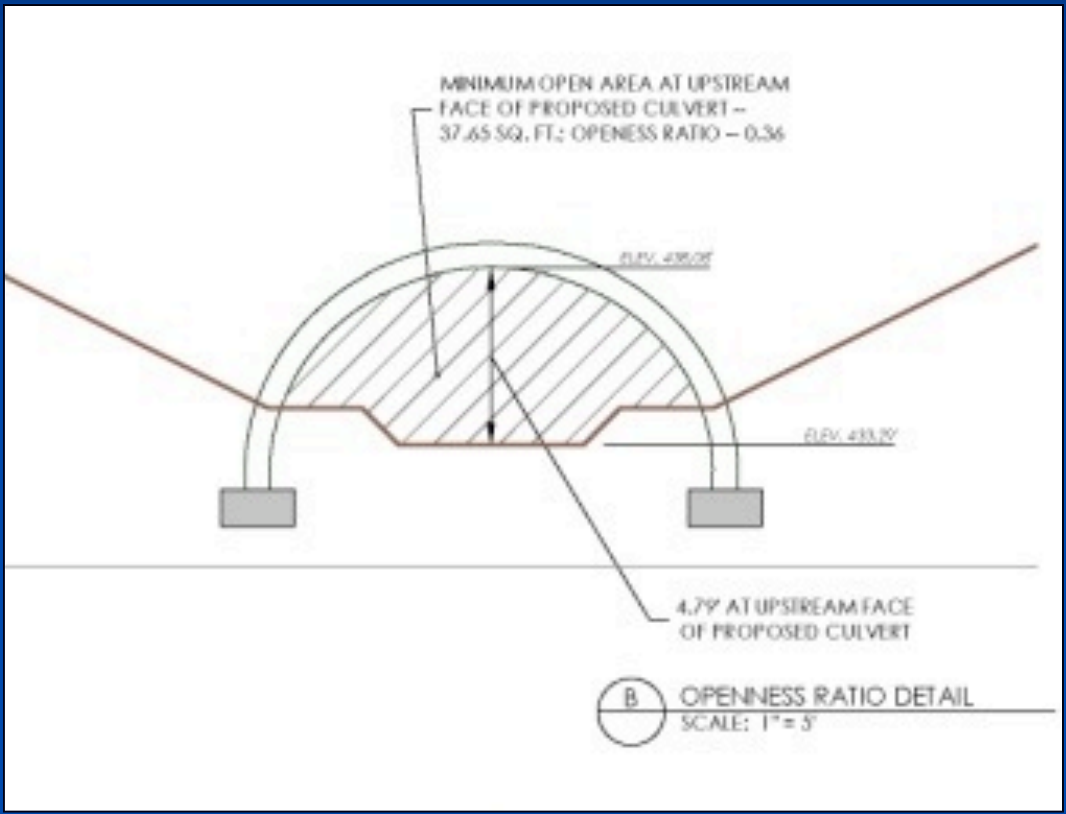
DATE:	APRIL 30, 2010
PROJECT NO.:	1034.001
SCALE:	1"=5'
DRAWN BY:	JEH/PW
CHECKED BY:	GMG

SHEET NO. 4 OF 8



Design Features: Planview

- Perpedicular alignment
- Laterally contained
- Boulders in banks & mid-channel to provide varied hydraulic habitat
- Boulders sized to withstand high flows (24-26”)
- Continuous banks
- Low flow channel



Design Features: Cross-sections

- Openness 0.36 m
- Cross-sectional area 37.65 SF min.
- 4.8 FT rise min.

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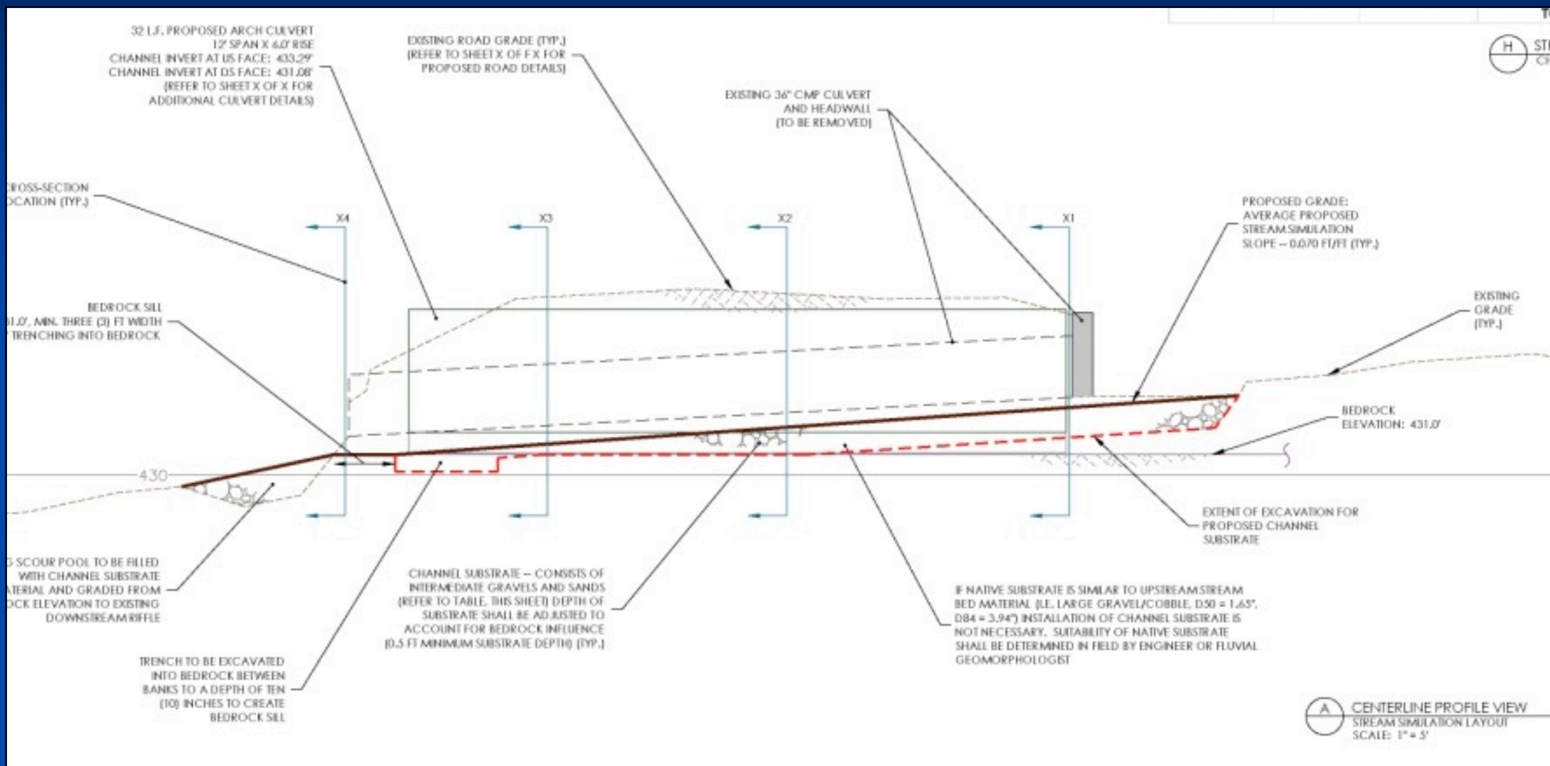
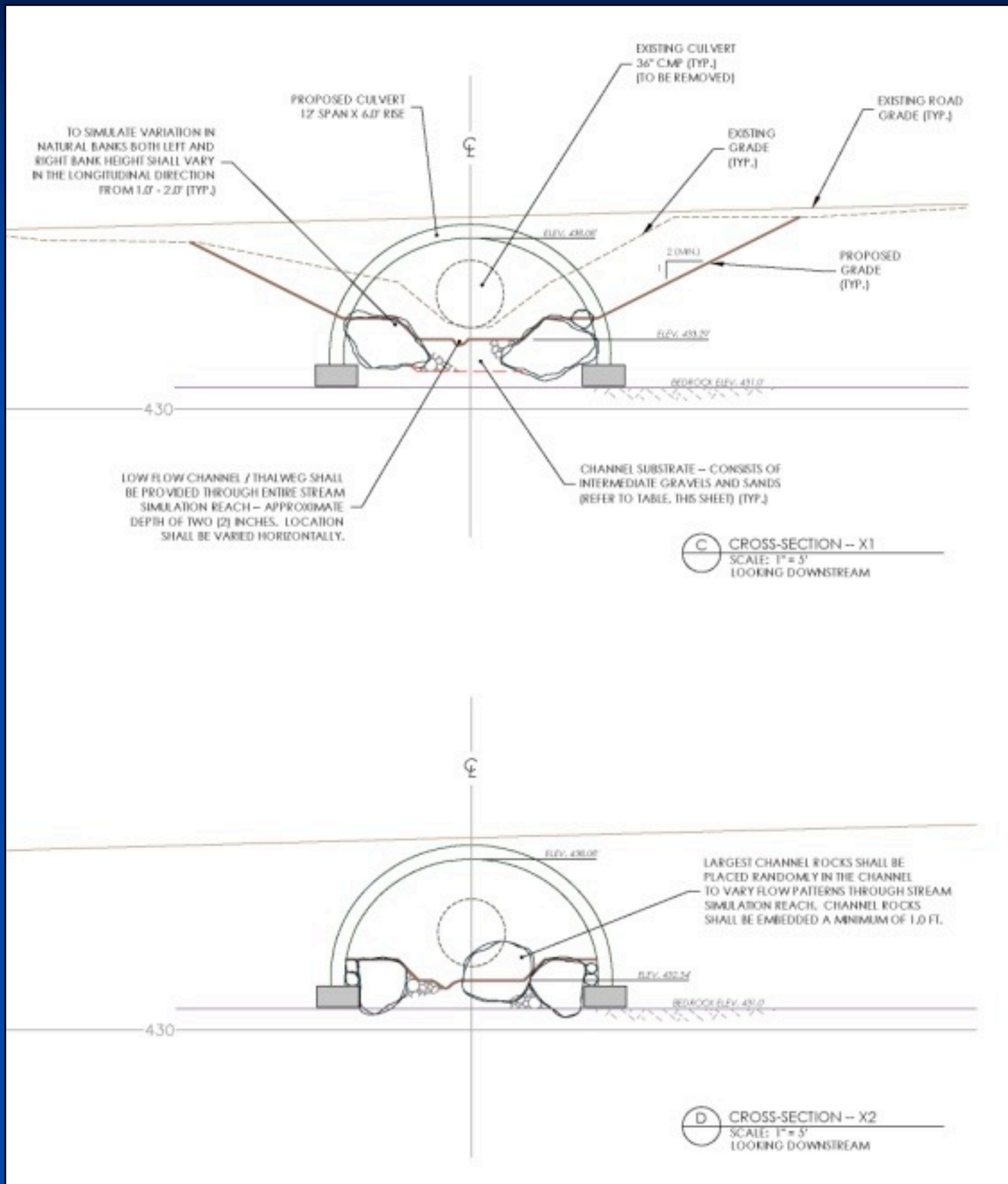
pH



Design Features: Profile

- US / DS Control Points
- Proposed Slope (7%) / Length consistent w/ US riffle
- Substrate depth to vary w/ bedrock
- Scour pool to be filled



Design Features: Cross-sections

- 12’ span x 6’ rise
- Adequate Width (1.2 x bankfull)
- Existing culvert
- Low flow channel
- Boulder placement in Banks & midchannel
- Continuous bank lines

Design Features: Bed Gradation

CHANNEL ROCK SPECIFICATION				
TYPE	ROCK CLASS	APPROX WEIGHT	MEDIAN AXIS	QUANTITY
BANK	ROCK-24	630	24" +/- 4"	80
RANDOM	ROCK-36	2,120	36" +/- 6"	10
			TOTAL WEIGHT:	35.8 TONS

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FINE MATERIAL GRADATION SPECIFICATION				
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50	#40	50	50% of volume is smaller than #40	1.9
			TOTAL VOLUME:	3.8 CY

H STREAM SIMULATION MATERIALS TABLE
CHANNEL SUBSTRATE AND CHANNEL ROCKS

- Mimic particle size distribution of US riffle
- Increase fine sediment fraction (pebble count bias)
- Convert to US Seive sizes for contractor / quarry
- Size boulders to resist high flows

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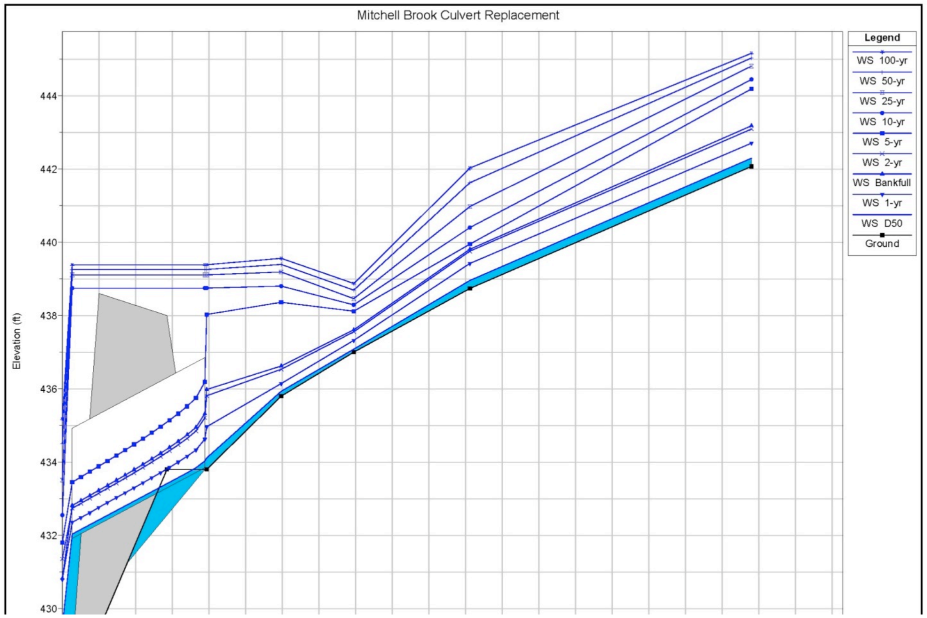

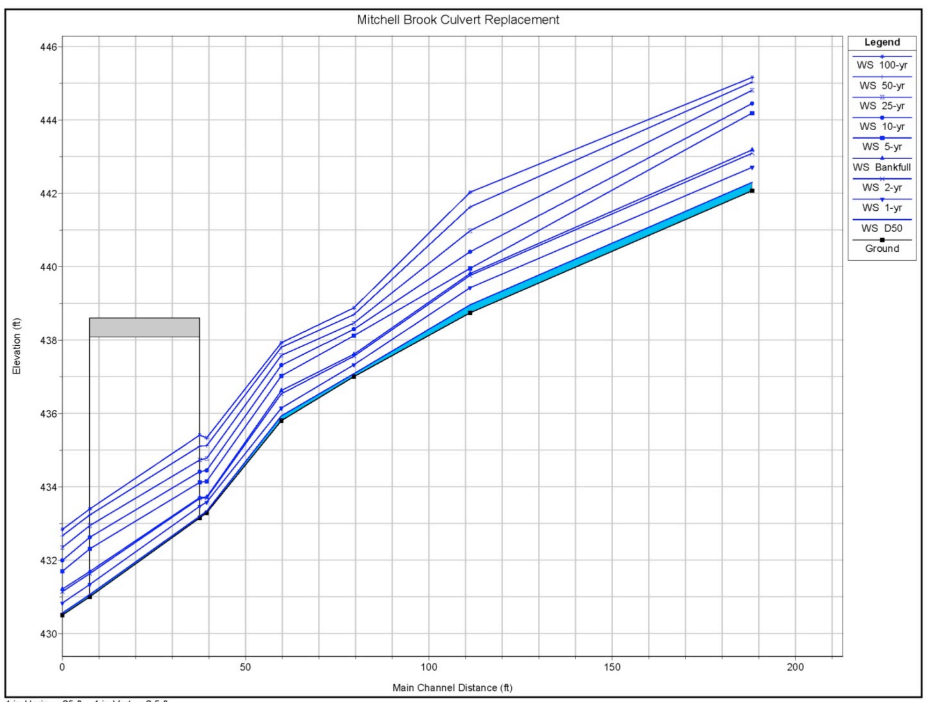

1 in Horiz. = 25 ft 1 in Vert. = 2.5 ft

HEC-RAS modeling

- Increased cross-sectional area increases flood capacity (25-yr overtopping flow)
- Results used to size boulders
- Results between simulated reach and upstream reach showed generally consistent velocities, depths and shear stresses

Related PH Project

Working with PA Trout Unlimited (Bucks County Chapter) to assess all road crossings in Cooks Creek watershed (Delaware River tributary)

- Identified all stream crossings (~100)
- Developed assessment protocol
- Trained volunteers for initial field assessment
  - Prioritize crossings
  - Conduct follow-up assessments
  - Develop conceptual restoration plans
- Possibly first in PA

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Resources

UMASS River and Stream Continuity Project

www.streamcontinuity.org

MA Riverways Program

www.mass.gov/dfwele/der/riverways/index.htm

USFS Stream Simulation Manual

http://www.fs.fed.us/eng/pubs/pdf/StreamSimulation/index.shtml

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Discussion

Bankfull Characteristics Comparison

USGS Regression Equations	NE Eqs. [1]	MA Eqs. [2] DA	MA Eqs. [2] DA & MBS	Field Survey Data (PH1)	Field Survey Difference * (%)	HEC-RAS Model Results [3]	HEC-RAS Model Difference * (%)
Drainage Area (sq. mi.)	0.36	0.38	0.38	-----	-----	-----	-----
Bankfull width (ft)	8.41	11.10	11.00	9.95	-10.0	7.03	-44.0
Bankfull mean depth (ft)	0.73	0.70	0.80	1.24	43.1	1.08	29.8
Bankfull cross-sectional area (ft^2)	5.95	7.20	8.40	9.34	10.6	4.59	-58.7
Bankfull discharge (ft^3/s)	17.28	14.50	21.10	-----	-----	21.1	-----

(1) As obtained from USGS abstract entitled Equations for Estimating Bankfull-Channel Geometry in Northeastern US

(2) As obtained from G. Bent (USGS), via email correspondence using MA specific eqs., using drainage area (DA) and both DA and Mean Basin Slope (MBS) as explanatory variables

(3) HEC-RAS model results, using existing conditions. Values shown are reach averages for Mitchell Brook upstream of culvert

* Difference calculated using USGS MA eqs. With DA & MBS

Culvert Retrofitting: Making the Case

- Dams in MA -- >2,900 dams (ASDSO 2008)
- Stream Crossings in MA -- > 28,500 road and railroad crossings (MA Riverways GIS)
- MA crossings outnumber dams ~10x
- Significant potential impact
- Need for restoration

Regional Efforts

- Guidelines/standards
  - MA River and Stream Crossing Standards (2006)
  - CT Stream Crossing Guidelines (2008)
  - VT Stream Crossing Guidelines (2009)
  - NH Stream Crossing Guidelines (2009)
- UMASS River and Stream Continuity Project
  - Volunteer assessments of road-stream crossings in MA and NE states

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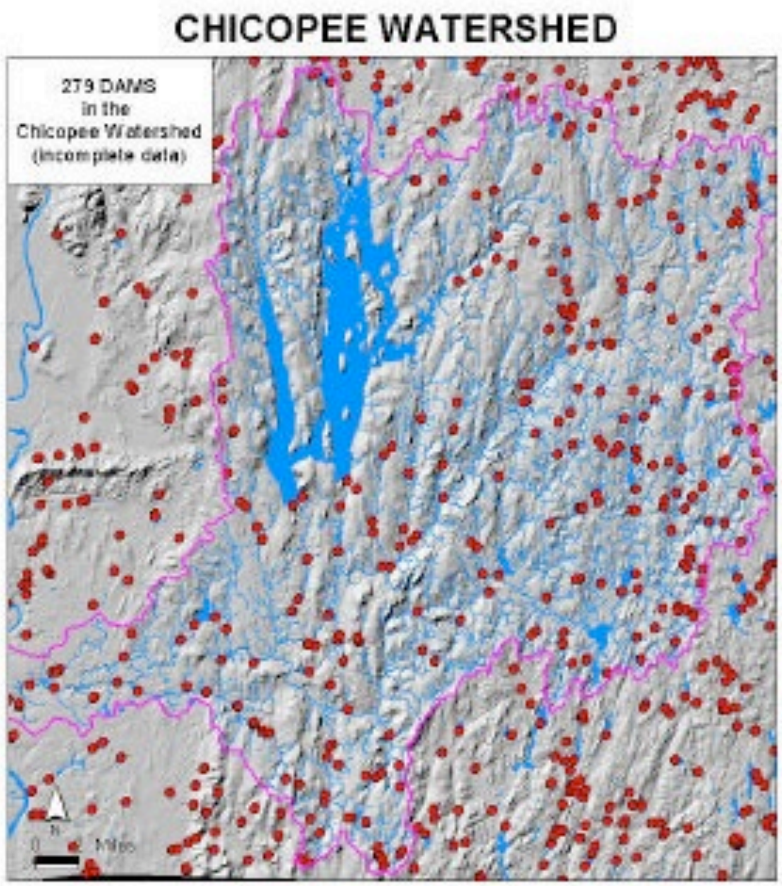
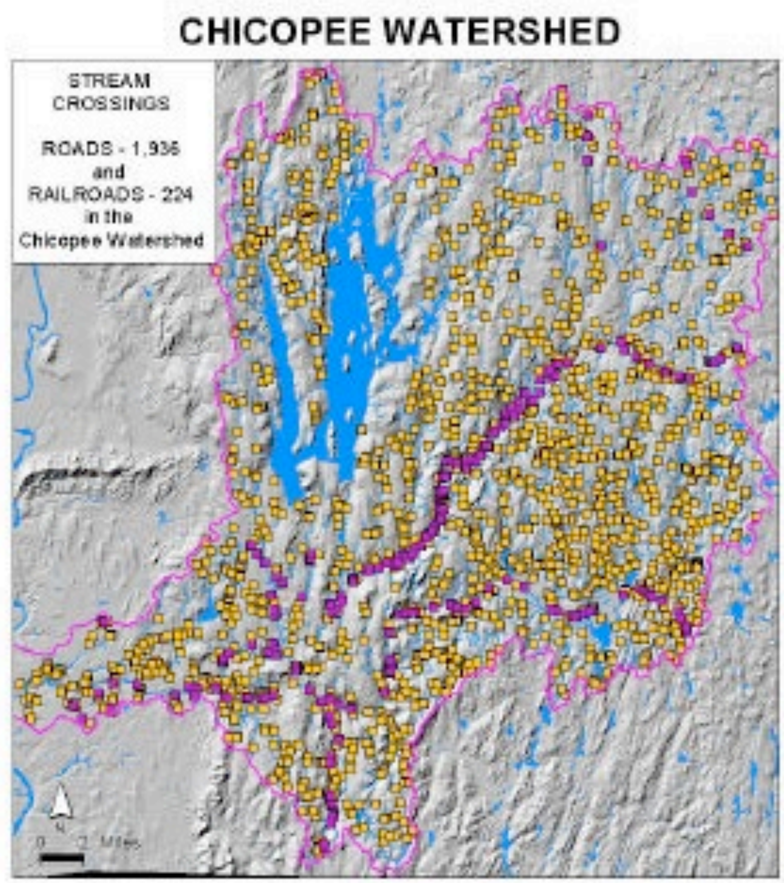
The Geographic Scope of River & Stream Fragmentation in Massachusetts
(Courtesy of the Massachusetts Riverways Program)



A legacy of early American small-scale industrialization, there are at least 279 dams on the tributaries and mainstem of the Chicopee River.



The intersection of the stream network with roads and railroads results in an estimated 2,160 crossings.